Modeling and Simulation of High Voltage Circuit Breaker Based on PSCAD

Tie Chen[1,2] and Haoyun Ke[1,2]

[1]College of Electrical Engineering and New Energy, China Three Gorges University, Yichang, China
[2]Hubei Provincial Key Laboratory for Operation and Control of Cascaded Hydropower Station, China Three Gorges University, Yichang 443002, China

Abstract—**The black box model can describe the process with only a few related parameters and avoid the complicated description like the physical mathematical model. Based on these advantages, a black box model of circuit breaker based on arc was established. Firstly, the two typical arc black box models were analyzed and compared, and the intelligent recognition scene of the detection module was established. The parameter identification of the least squares model was used to select the intelligent arc model. The black box model and simulation circuit of the circuit breaker were built in the PSCAD simulation software, and the model was programmed by calling the MATLAB program through its special interface. Based on the established circuit breaker model, the voltage and current when the circuit breaker cuts different faults in different scenes are basically consistent with the theoretical analysis through simulation research and comparison. The correctness and versatility of the model are verified, which indicates that the design model has certain reference.**

Keywords—*circuit breaker; arc; pscad; matlab; black box mode*

I. INTRODUCTION

Circuit breaker is the most important control and protection equipment in power system[1], and its breaking process has always been one of the key points of circuit breaker modeling. During the interruption process, the interaction between the arc and the circuit will lead to a series of effects, such as the increase of the system voltage, the breaking ability of the circuit breaker, etc[2,3]. The Arcing characteristics of the arc involve the physical process and coupling calculation of electromagnetic field, air flow field and temperature field, and the process is extremely complex[4]. The study of arc model can be divided into two categories: one is based on fluid dynamics, thermodynamics and Maxwell equations, which focuses on describing the physical shape of arc by complex mathematical methods [5,6]; the other is a black box model which focuses on describing arc behavior and studying the relationship between arc conductance and other variables in the circuit[7,8].

Although the physical model reveals the arcing process and extinguishing process of the arc deeply, and tries to describe a dynamic physical process by a subtle mathematical method. Its related conditions become very complicated and difficult to solve because it describes various physical processes very hard. The black box model simplifies the arcing process and quenching process greatly, and only focuses on the external characteristics of the circuit. The process is equivalent to the dynamic resistance to study the phenomenon of over-voltage caused by arcing, thus avoiding the complicated description like the physical mathematical model.

In this paper the black box model of circuit breaker is studied. Based on the typical black box model, the current scene can be recognized intelligently and automatically as a dynamic resistor with different arc parameters, and then the model can be matched automatically according to the scene. In the PSCAD/EMTDC power system transient simulation software, the arc parameters are identified. The arc black box model is established and interacted with MATLAB. Finally, the intelligent simplified model which can reflect the characteristics of external circuit and express the internal characteristics of circuit breaker is completed.

II. ANALYSIS AND ESTABLISHMENT OF CIRCUIT BREAKER SIMULATION MODEL

A. Model Structure of Circuit Breaker

Figure 1 is the model state diagram. When the system is running normally, the circuit breaker only has a contact resistance R0 (1 ohm). After the failure occurs, the black box arc model needed for the intelligent selection of the model is presented as an arc resistance Rarc externally. After the failure is successfully cut off, it will eventually be regarded as resistance Roff.

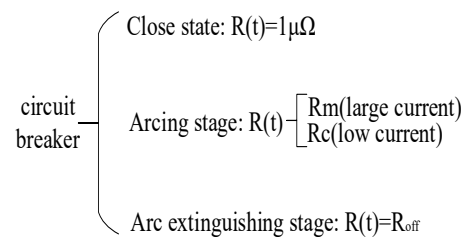FIGURE I. MODEL STATE DIAGRAM

B. Arc Model Selection Criteria

(1)Mayr arc model

The Mayr model is derived from three basic theories: thermal inertia, heat balance and thermal ionization. The formula is as follows:

$$\frac{1}{g_m}\frac{dg_m}{dt} = \frac{1}{\tau_m}\left(\frac{ei}{N_0}-1\right) \qquad (1)$$

In the form: g_m —electric arc conductance;

e— arc potential gradient;

i— arc current;

N_0— the power of arc cooling;

τ_m— arc time constant.

In China, most of 3~66kV distribution network are low current systems because of the consideration of system reliability, operation economy and power supply quality. Under steady arc condition, $dg_m / dt = 0$. It can be obtained, $ei = N_0$. The arc voltage gradient is proportional to the square root of the arc resistance, which corresponds to the volt-ampere characteristics of the arc in the case of low current. Therefore, the model is suitable for the modeling of low current arcing.

(2)Cassie arc model

Cassie arc model assumes that the gas passage shape of the arc is constant, and the energy dissipation is caused by the change of gas flow or arc column related to gas flow. The velocity of energy dissipation is related to the change of arc column cross-sectional area [9]. The Cassie arc model is as follows:

$$\frac{1}{g_c}\frac{dg_c}{dt} = \frac{1}{\tau_c}(\frac{u_{arc}^2}{u_c^2}-1) \qquad (2)$$

In the form: g_c— electric arc conductance;

τ_c— arc time constant;

U_{arc}— arc voltage;

U_C— arc static voltage.

The main characteristic of switching application in large current system is that its rated current value is large. Its application should include generator outlet protection, impulse current switching and other large current application fields besides short circuit fault of protection system. Compared with the small current power switch, its breaking current value is larger, and its influence on thermal effect, force effect, magnetic effect and electrochemical effect is more severe, even can determine whether the circuit breaker can control and protect the system normally. Under steady arc condition, $dg_c / dt = 0$. It can be obtained, $u_{arc} = u_c$. It corresponds to the volt-ampere characteristics of the arc in the case of large current. Therefore, the model is suitable for the modeling of large current arcing.

C. *Parameter Identificatin of Arc Model*

Because the arc extinguishing process in the chamber of the circuit breaker is a complex physical change, the parameters are not constant in practice. It is particularly important to determine the parameters before simulation. The key problem of Mayr arc model simulation is to determine the time constant and arc cooling power, while the key problem of Cassie arc model is to determine the time constant and static voltage value [11]. Rewrite (1), (2) as follows:

$$F_m = \frac{dg_m}{dt} = \frac{g_m}{\tau_m}(\frac{ei}{N_0}-1) \qquad (3)$$

$$F_c = \frac{dg_c}{dt} = \frac{g_c}{\tau_c}(\frac{u_{arc}^2}{u_c^2}-1) \qquad (4)$$

In order to get τm, N0, τc and UC, we will rewrite (3), (4) as follows:

$$F_m = ap(t) - bq(t) \qquad (5)$$

In the form: $a = \dfrac{1}{\tau_m N_0}$, $b = \dfrac{1}{\tau_m}$, $p(t) = g_m \cdot e \cdot i$, $q(t) = g_m$.

$$F_c = ap(t) - bq(t) \qquad (6)$$

In the form: $a = \dfrac{1}{\tau_c u_c^2}$, $b = \dfrac{1}{\tau_c}$, $p(t) = g_c \cdot u_{arc} \cdot u_{arc}$, $q(t) = g_c$.

Then by using the least square method in MATLAB, the required values of each arc model are obtained before the simulation calculation, as shown in the following forms:

$$\min J(\tau, N_0) = \min \sum_k [ap(t_k) - bq(t_k) - F(t_k)]^2 \qquad (7)$$

$$\min J(\tau, u_c) = \min \sum_k [ap(t_k) - bq(t_k) - F(t_k)]^2 \qquad (8)$$

$$\tau_m = \tau_c = \frac{1}{b} \qquad (9)$$

$$N_0 = u_c = \frac{b}{a} \qquad (10)$$

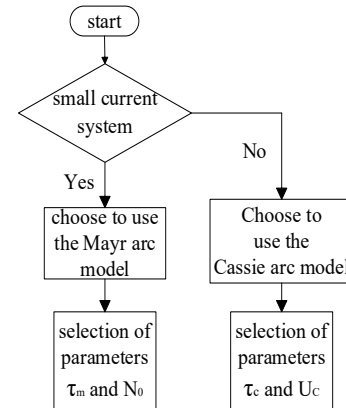The matching process of the arc model is shown in Figure 2:

FIGURE II. ARC MODEL MATCHING PROCESS

III. ESTABLISHMENT OF CIRCUIT BREAKER SIMULATION MODEL

A. *Circuit Breaker Modeling*

(1)Detection section

The model intelligently identifies the state of the scene and detects whether it is a large current system or a small current system or whether there is a fault. After the breaker is switched on, the zero-point detection module is used to detect whether the current is zero-crossing and zero-crossing position. And then the current is zero, check whether the resistance is up to the set value and determine whether the fault can be successfully cut off.

(2)Control section

It will intelligently match arc model after scene detection. If the circuit breaker is in a closed state, the control of its non-action is equivalent to the ordinary conductor. If a fault occurs, the time-controlled switch logic module is used to control the breaker contact separation. When the resistance reaches the set value, the circuit breaker is controlled to maintain the state of tripping, and the fault is successfully cut off.

(3)Calculation section

After the arc model matching, based on formula (7) and (8) the least squares method is used to get the parameters and set up the model. After switching on, the real-time dynamic resistance value is obtained by the calculation module, and the value is transferred to the variable resistance element.
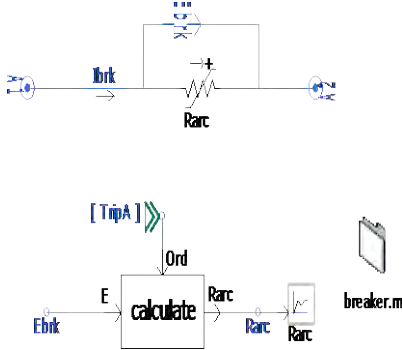
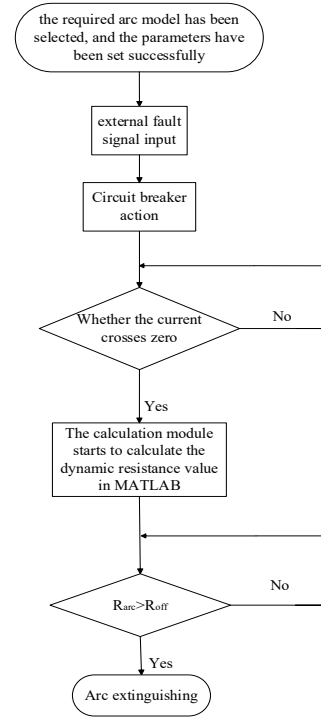FIGURE III. PARTIAL EQUIVALENT MODEL OF CIRCUIT BREAKER

FIGURE IV. THE FLOW CHART OF CIRCUIT BREAKER CALCULATION

B. *Introduction to Simulation Software*

PSCAD / EMTDC power system electromagnetic transient simulation software has the advantages of accurate model and high quality simulation, while MATLAB has superior data calculation and processing capabilities. Combining the advantages of the two software together can get more accurate simulation results, and can achieve complementary advantages of the two software [12,13].

In PSCAD, Fortran subroutine is called by DSDYN. This Fortran subroutine is used to start MATLAB program and run M file, so as to realize the data connection between PSCAD and MATLAB. Users can write the required program according to the simulation needs [14]. Circuit breaker simulation model data transmission is shown in Figure 5.
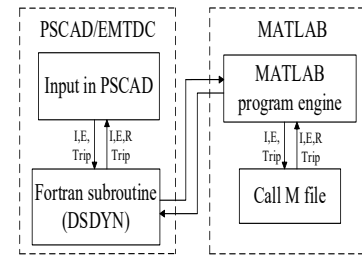
FIGURE V. DATA TRANSMISSION DIAGRAM OF CIRCUIT BREAKER SIMULATION MODEL.

IV. ESTABLISHMENT OF SIMULATION SYSTEM

A. *Simulation Circuit*

The simulation circuit is shown in Figure 6. The simulation step size is 50 μs, the rated resistance is 1μΩ when the circuit breaker is on. Through the MATLAB, τ_c is 257.3μs and U_C is

165.8kV in Cassie arc model; τ_m is 79μs and N0 is 24787W in Mayr arc model.

The fault points are the breaker outlet and transformer outlet(both are three-phase symmetrical short-circuit faults).
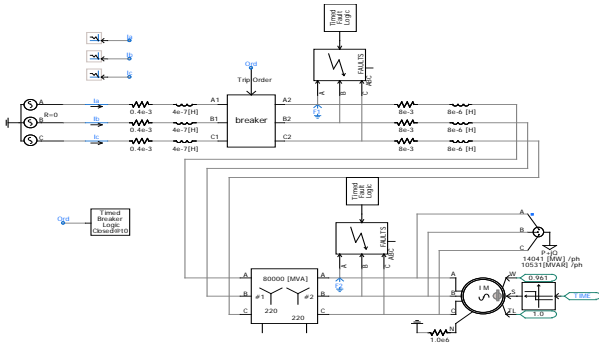

FIGURE VI. THREE PHASE SIMULATION CIRCUIT

B. *Analysis of Simulation Results*

In the large current system, when the breaker outlet fault occurs, the breaker starts to operate after 10.5ms of fault and current completely cut off 8ms later. The three-phase voltages on the circuit breaker have transient impulse voltages of 0.25ms, 0.27ms and 5ms respectively, and there is no reburning phenomenon. As shown in Figure 7 and Figure 8. When the fault occurs at the outlet of the transformer, the circuit breaker starts to operate after 11.25ms of fault, and the current is completely cut off after 5.25ms. The three-phase voltages on the circuit breaker have transient impulse voltages of 0.25ms, 0.25ms and 0.25ms respectively, and there is no r eburning phenomenon. As shown in Figures 9 and 10.
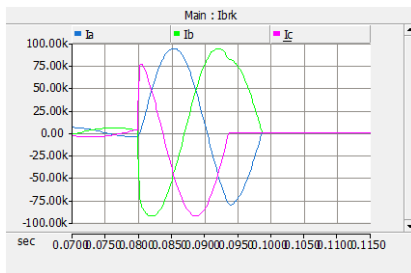

FIGURE VII. THE THREE-PHASE CURRENT OF FAULT AT THE OUTLET OF THE CIRCUIT BREAKER
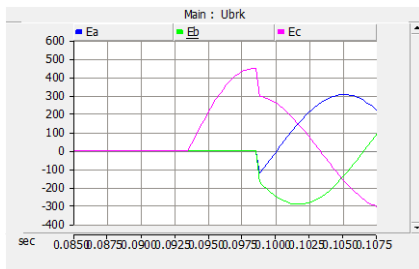

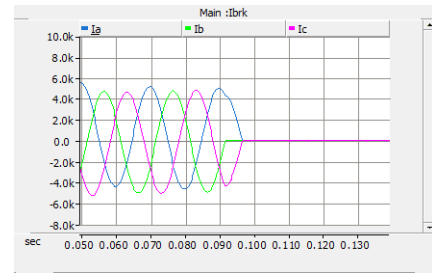FIGURE VIII. THE THREE-PHASE VOLTAGE OF FAULT AT THE OUTLET OF THE CIRCUIT BREAKER

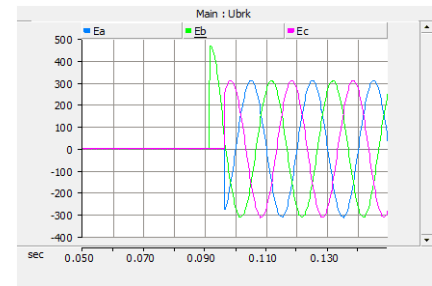FIGURE IX. THE THREE-PHASE CURRENT OF FAULT AT THE OUTLET OF THE TRANSFORMER

FIGURE X. THE THREE-PHASE VOLTAGE OF FAULT AT THE OUTLET OF THE TRANSFORMER

Under the condition of small current system, when the breaker outlet fault occurs, the breaker starts to operate after 13.75ms, and the current is completely cut off after 5ms. The three-phase voltages on the circuit breaker have transient impulse voltages of 0.25ms, 0.25ms and 5.25ms respectively, and there is no reburning phenomenon. As shown in Figures 11 and 12. When the fault occurs at the outlet of the transformer, the circuit breaker starts to operate after 11ms of the fault, and the current is completely cut off after 4.75ms. The three-phase voltages on the circuit breaker have transient impulse voltages of 4ms, 0.25ms and 0.25ms respectively, and no reburning occurs. As shown in Figure 13 and Figure 14.
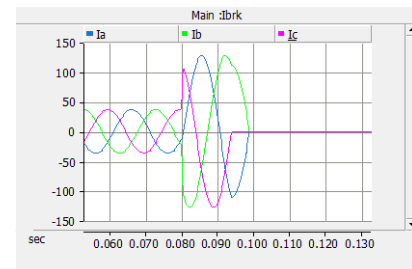

FIGURE XI. THE THREE-PHASE CURRENT OF FAULT AT THE OUTLET OF THE CIRCUIT BREAKER
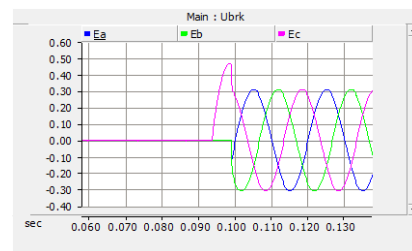

FIGURE XII. THE THREE-PHASE VOLTAGE OF FAULT AT THE OUTLET OF THE CIRCUIT BREAKER
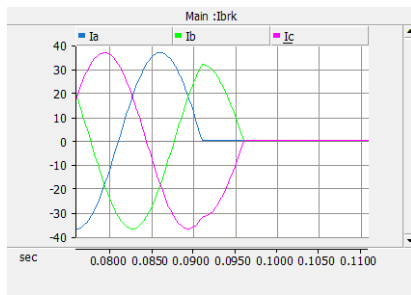
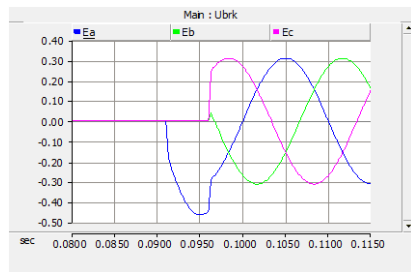FIGURE XIII. THE THREE-PHASE CURRENT OF FAULT AT THE OUTLET OF THE TRANSFORMER

FIGURE XIV. THE THREE-PHASE VOLTAGE OF FAULT AT THE OUTLET OF THE TRANSFORMER

V. CONCLUSION

The arc based black box model of circuit breaker is established, and two typical arc models are analyzed. The required model parameters are obtained by using the least square method, and the intelligent arc model is selected by taking the large and small current system as the boundary. The simulation results show that the circuit breaker model based on the advantages of PSCAD and MATLAB can identify the system state automatically and correctly, and the voltage and current when different faults are cut off are basically consistent with the theoretical analysis. The correctness of the model is verified, which indicates that the design model has certain reference and versatility.

ACKNOWLEDGMENT

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